THE FOCUSED ION BEAM MICROSCOPE AS A MULTIFUNCTIONAL TOOL IN MATERIALS SCIENCE TO UNDERSTAND PRINCIPLE MECHANISMS OF DAMAGE AND FATIGUE

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The Focused Ion Beam microscope (FIB) can be used as multidisciplinary instrument in materials science. This will be shown here with four different examples. First, it will be shown how the FIB can be used to initiate artificial cracks for fatigue life investigation. The second example handles with the FIB-tomography, which is a high-resolution micro-tomography and can be used to investigate the behavior of microstructures under loading. In the third and fourth case, the FIB is used to cut small micro-compression and micro-bending specimens to investigate the influence of the orientation of neighboring grains and size effect on the macroscopic deformation behavior. Let us consider some more details: For the first example, there are several papers that describe the initiation of notches by FIB to start fatigue cracks in a desired position; however, there is one very special technique described in [1] which allows the initiation of stage-I fatigue cracks exactly on the slip system with the highest Schmid factor. Therefore, one has to measure the crystal orientation of the grain that should contain the stage-I crack by Electron Back Scatter Diffraction (EBSD). Consequently, one can calculate the Schmid factors of all slip systems and determine the slip system with highest Schmid factor. Then one has to rotate the specimen in the FIB in the correct position to cut the notch parallel to this plane. With a precise surface profile it is possible to initiate penny shaped short cracks which are nearly identical with natural short fatigue cracks but with a desired length, depth and position. The second example for the use of the FIB is the micro-tomography after the fatigue experiment [2]. In this case, it was of interest, how the crack interacts with the grain boundary. According to the geometrical model of Zhang, the problem is three-dimensional and not only depending on the position of the crack planes but also on the exact position of the grain boundary. In this investigation it was shown that there is nearly no resistance of a grain boundary against crack propagation, if the planes on which the crack propagates preferentially in both neighboring grains intersect on the grain boundary. Contrary, if the both crack planes form a larger angle on the boundary, there is a large resistance of the boundary found against crack transmission. This could even be determined qualitatively by calculating the local stress intensity factor at the grain boundary, which is caused by the dislocation pile up of the dislocations emitted from the crack tip in the direction towards the boundary. In the third experiment, micro-compression-test samples (micro-pillars) were cut by the FIB to investigate the transmission of dislocations through boundaries for plastic deformation without a crack [3]. Thereby the pillars can be cut in such a way, that they contain a grain boundary in their middle. The orientation of both neighboring grains can be selected by a prior EBSD measurement. Thereby it was found that the mechanism to transmit a grain boundary in this case is the same as in the case of a crack growing towards the boundary, however with one difference: For the crack the dislocation source is only on one side of the grain boundary and only a single slip system was activated. By the STRONG (Slip Transfer Resistance Of Neighboring Grains) method the strength of a grain boundary can be calculated from the orientation of both neighboring grains only and this can be used to determine the hardness of the pillar which can be measured during in situ compression with a nanoindenter. The Last experiment described here based on using the FIB is cutting samples for fatigue of micro-bending beams. However, in this case again, there is not only the bending beam cut by FIB but also an initial notch to investigate fatigue crack growth. This can also be cut on the plane with the highest Schmid factor in a single slip oriented grain. By this experimental set up, the influence of the neutral axis in the middle of the bending beam in combination with the size effect of micro-specimens and the Bauschinger effect can be investigated. It was found that the micro bending beams show an increased strength against fracture by a factor of ten. This could be clearly demonstrated by excluding all other influences. In summary, by constructing experiments and excluding as many disturbing parameters as possible, the simple but still unknown mechanisms of plastic deformation and fatigue can be investigated on the micro-scale.

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ACKNOWLEDGMENTS

The authors are indebted to Horst Vehoff and Christian Motz for many valuable discussions. We gratefully acknowledge the financial support by the Deutsche Forschungsgemeinschaft (DFG)

FIGURES

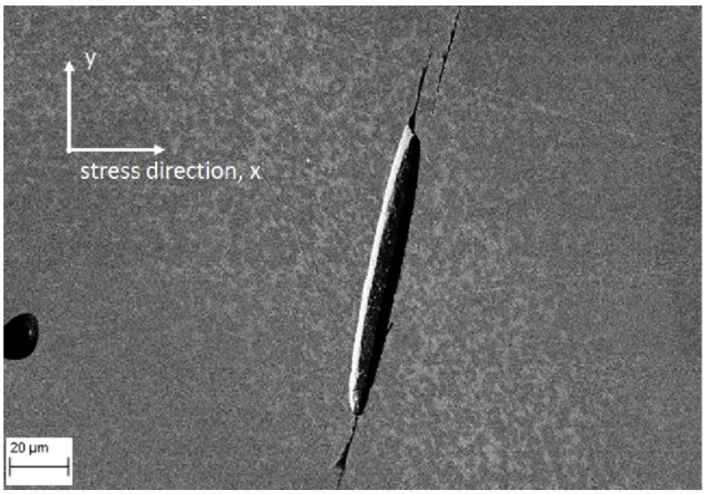

Fig. 1: Artificial micro-crack growing from a FIB notch cut on the slip plane with the highest Schmid factor.

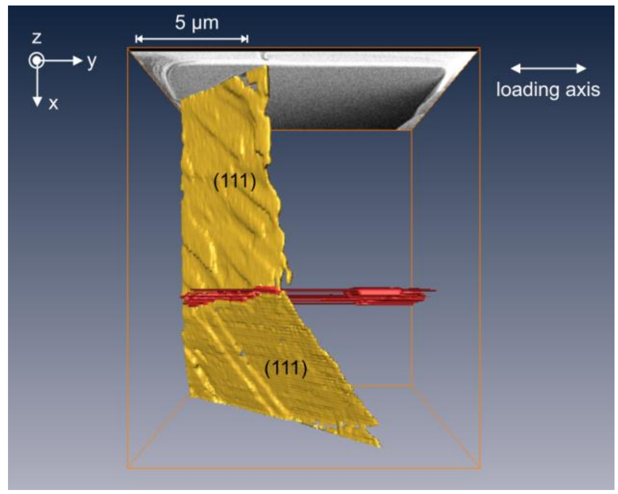

Fig. 2: Micro-tomography of a crack (yellow) growing through a grain boundary (red) with the intersection line of both slip planes on the boundary. The result is nearly no resistance of the boundary against crack propagation.

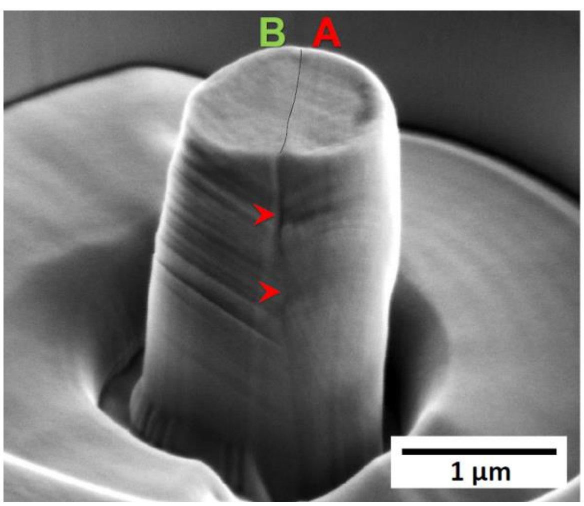

Fig. 3: Micro-compression-test samples of a bicrystal after the compression test (grain

Fig 4: Micro-bending beam with an artificial fatigue crack (the beam thickness is 10 µm).